Mapping digital competence : Students' maker literacies in a school's makerspace

Kumpulainen, Kristiina

2020-06-02

Kumpulainen , K , Kajamaa , A , Leskinen , J , Byman , J & Renlund , J 2020 , ' Mapping digital competence : Students' maker literacies in a school's makerspace ' , Frontiers in education , vol. 5 , 69 . https://doi.org/10.3389/feduc.2020.00069

http://hdl.handle.net/10138/315957
https://doi.org/10.3389/feduc.2020.00069

frontiers in Education

ORIGINAL RESEARCH
published: 02 June 2020
doi: 10.3389/feduc.2020.00069

Check for updates

Mapping Digital Competence: Students' Maker Literacies in a School's Makerspace

Kristiina Kumpulainen, Anu Kajamaa, Jasmiina Leskinen, Jenny Byman and Jenny Renlund*

Faculty of Educational Sciences, University of Helsinki, Helsinki, Finland

This study investigates and maps students' maker literacies as they relate to digital competence. The study builds on sociocultural theorizing and on the scholarship of digital literacy that defines maker literacies as social practices that entail making and remaking artifacts and texts using various materials and technologies. Through a detailed multimodal analysis of video data from an ethnographic case study of students' (N:11) interaction in an elementary school's makerspace in Finland, our study presents and applies a framework of analysis for maker literacies and discusses how the school's makerspace enhanced the students' digital competence across operational, cultural, and critical dimensions. The study shows how the makerspace context afforded the students ample opportunities to engage in the operational dimension of maker literacies. However, there was less engagement in cultural and critical literacies. The implications of these findings for students' digital competence in makerspaces are discussed.

Keywords: digital competence, maker literacies, makerspaces, education, video research, multimodal analysis

OPEN ACCESS

Edited by:
*Marina Milner-Bolotin,
University of British Columbia, Canada*

Reviewed by:
*Heather Moorefield-Lang,
University of North Carolina at Greensboro, United States
James Gauthier,
University of British Columbia, Canada*

***Correspondence:**
*Kristiina Kumpulainen
kristiina.kumpulainen@helsinki.fi*

Specialty section:
This article was submitted to STEM Education, a section of the journal Frontiers in Education

Received: *23 March 2020*
Accepted: *05 May 2020*
Published: *02 June 2020*

Citation:
Kumpulainen K, Kajamaa A, Leskinen J, Byman J and Renlund J (2020) Mapping Digital Competence: Students' Maker Literacies in a School's Makerspace. Front. Educ. 5:69. doi: 10.3389/feduc.2020.00069

INTRODUCTION

The importance of digital competence for social inclusion, employability, and quality of life is widely recognized. There is a need for every citizen to develop relevant knowledge, skills, and attitudes to be able to participate in a complex and increasingly digitalized society. According to the Digital Competence framework set forth by the European Commission (Carretero et al., 2017), the key areas of digital competence include information and data literacy, communication, and collaboration, digital content creation, and safety and problem solving. Following European recommendations, digital competence is listed in the Finnish government's key projects, emphasizing confident, productive, creative, and critical usage of digital technologies for diverse purposes in various social contexts (Ala-Mutka, 2011). Also, the recently implemented Finnish core curriculum for K-12 education underscores digital competence as a subset of the so-called transversal competence that every student should be entitled to develop (Finnish National Agency for Education, 2016).

Although many children in the Global North have access to media, digital tools, online sites, and apps in their homes and communities (EU Kids Online, 2014; Suoninen, 2014; Livingstone et al., 2017), there is a growing concern that young people's digital competence is inadequate and unevenly distributed (Ferrari, 2013; Chaudron et al., 2018). Young people are reported to be adept in using technologies for operational purposes, but they generally lack more advanced competence, such as critical literacy (Ala-Mutka, 2011). These findings indicate that mere exposure to digital technologies does not equate with the development of more advanced digital competence

(Hakkarainen et al., 2015). Further, not all young people have equal opportunities to engage with and learn and from digital technologies and to develop their digital competence. This is due to a range of social and cultural factors and a lack of interest, confidence, or social support (Livingstone et al., 2017; Chaudron et al., 2018). Research also demonstrates that digitally-enhanced learning opportunities are provided unevenly to students in formal education (Ilomäki and Lakkala, 2011; Palaiologou, 2016). These realities point to the need for further research and educational development to ensure every child's right to acquire digital competence early in life.

In this study, we address current needs in relation to the enhancement of young people's digital competence by drawing on an ethnographic case study of students' maker literacies in the makerspace of a Finnish elementary school. Our work extends the concept of digital literacy to maker literacies that stand for social practices with and across digital technologies in a makerspace context (Marsh, 2020). Despite earlier research on makerspaces, so far little research attention has been directed to the characteristics of students' maker literacies as they relate to digital competence. Maker literacies represent a practice-oriented approach to digital literacy and digital competence. Maker literacies move us beyond viewing competence as distinct skills in relation to digital technology to researching and understanding digital competence in relation to skills, knowledge, and attitudes as they are worked into students' everyday social practices with digital technologies and other tools in a makerspace context.

Our motivation for this study was twofold; first, we wanted to develop an analysis framework to account for students' maker literacies in a school's makerspace, and second, by applying this analysis framework we wanted to illustrate how it can generate new research knowledge on maker literacies with special consideration being given to students' digital competence. Through a detailed, multimodal analysis of students' maker literacies, we sought to grasp the nuanced ways maker literacies relate to and potentially enhance students' digital competence.

In the next section, we discuss existing research knowledge on makerspaces. We then define and theorize our study and its key concepts. This is followed by an introduction to our ethnographic case study and our analysis framework before sharing and discussing our empirical findings. We end our article by considering the educational potential of makerspaces in enhancing students' digital competence.

ENHANCING STUDENTS' DIGITAL COMPETENCE: MAKERSPACES

Makerspaces have aroused educational attention as a potential means to accelerate technology integration in K-12 education and to democratize students' learning opportunities, particularly in the fields of science, technology, engineering, and mathematics (STEM; Honey and Kanter, 2013; Halverson and Sheridan, 2014; Sheridan et al., 2014; Litts, 2015; Martin, 2015). Makerspaces prescribe a model of learning-by-doing in which individuals can work on creative and interdisciplinary projects, affording students opportunities to create, play, and experiment with a range of digital technologies, such as electronics, coding tools, game-making apps, laser cutters, and 3D printers (Resnick et al., 2000). Makerspaces can also include more traditional technologies and materials or hybrid combinations of non-digital and digital tools (Buechley et al., 2013; Blum-Ross et al., 2020).

A variety of benefits relevant to digital competence have been proposed to be the result of participating in makerspaces. Existing research suggests that hands-on experimentation and production across multiple digital tools and contents in makerspaces support students' creative and critical engagement with digital technologies (Ratto, 2011; Kafai et al., 2014). Designing and making digital games, stories, and animations and sharing them with others creates opportunities for students to learn not only computational thinking but also cultural literacies, that is, learning to participate in a given culture (Kafai and Burke, 2015; Portelance et al., 2015). Makerspaces can also foster children's playful interactions, exploration, and participatory learning (Burke and Crocker, 2020), and "maker citizenship" that is a concept that draws together understandings of making, digital literacies, and creative citizenship (Marsh et al., 2018).

Despite educationally promising findings on various makerspaces and their resonance with students' digital competence, available research evidence points out critical features that call for further attention. For instance, makerspaces have been criticized for their narrowly-defined goals and for failing to attract the broader population of young people (Blikstein and Worsley, 2016). Kafai et al. (2014) also remind us about the synergistic relationship between technology and aesthetics in makerspace settings and argue that makerspaces are not only about the technology itself, but are also about the aesthetic and cultural aspects of engaging and learning in makerspaces. In addition, research points out the need to address and promote students' critical literacies in makerspaces considering ethics, sustainability, and relationality (Guyotte, 2020; Marsh, 2020).

Our study responds to these calls and extends current research knowledge on the educational potential of makerspaces for students' maker literacies and digital competence. The makerspace context of our study was a FUSE Studio, a digital infrastructure for STEAM (Science, Technology, Engineering, Arts, and Mathematics) learning that engages students with design challenges (Stevens and Jona, 2017). Some of the design challenges are fully digital, some combine high-tech and low-tech tools, and some can be realized without the use of any digital technologies. The FUSE Studio creates a novel, yet less researched context to investigate and understand students' maker literacies and how they relate to digital competence. In our study, we asked:

- What characterizes students' maker literacies in the school's FUSE Studio?
- How do the identified maker literacies relate to digital competence?

TOWARD A FRAMEWORK FOR ANALYZING DIGITAL COMPETENCE THROUGH MAKER LITERACIES

The theoretical base of our study was framed by the sociocultural approach that places tool-mediated social interactions at the center of analysis of human learning and development (Vygotsky, 1987; Säljö, 1999; Ludvigsen et al., 2011). It holds that learning is an interactional process in which social practices and artifacts create a shared semiotic system for joint participation, modes of thinking, and learning. The starting proposition of the sociocultural approach is that individual ways of knowing and being are anchored in everyday social and cultural activities in which people participate. In turn, these everyday activities are shaped by the values and practices of communities (Gee et al., 1996; Barton et al., 2000). The sociocultural framing emphasizes the way in which learning and development are evidenced in qualitative changes in social practices as the result of construction of new knowledge, skills, and values (Kumpulainen and Renshaw, 2007).

We approached and analyzed students' digital competence from the scholarship of digital literacy. From a sociocultural view, digital literacy encompasses social practices that involve reading, writing, and multimodal meaning making through the use of a range of technologies (Sefton-Green et al., 2016; Marsh, 2020). Here, reading and writing are understood in their broadest terms involving accessing, using, analyzing, producing, and disseminating various "texts." Further, digital literacy can cross non-digital practices and material and immaterial boundaries, creating complex, and hybrid social practices for meaning-making and learning (Burnett et al., 2014). Hence, digital literacy involves a range of semiotic systems and multimodal resources with which students engage (Sefton-Green et al., 2016).

Recently, researchers interested in children's and young people's digital literacy practices in makerspaces have proposed "maker literacies" as a useful concept to acknowledge and attend to the nuanced nature of makerspaces as a social context for children's creative engagement with digital technologies and active participation in digital cultures (Rowsell and Wohlwend, 2016; Marsh et al., 2018). The term "maker literacies" stands for "sets of practices for making and remaking artifacts and texts through playful tinkering with materials and technologies" (Wohlwend et al., 2018, p. 148), situating semiotic meaning-making at the heart of the maker practice. Maker literacies enable attention to be given to multiple literacies that cross the boundaries between reading, science, art, mathematics, technology, and more (Pawloski and Wall, 2016). The term also attends to the creative dimensions of making. Maker literacies resonate with digital competence by directing attention to students' multimodal design and production, creative, and critical thinking, problem-solving, communication, and collaboration (Jenkins et al., 2009; Burnett, 2016).

Following recent research on maker literacies and digital literacy scholarship in general (Marsh et al., 2018; Marsh, 2020), our study drew on Green's 3D (1998) conceptual model of literacy, which holds that there are three inter-relating dimensions of literacy, namely, the operational, cultural, and critical. Operational elements are skill-based and include those skills needed to become a competent communicator, such as being able to decode and encode digital texts and artifacts, in addition to being able to use digital software and hardware. Cultural elements point to the understanding of literacy as a cultural practice and being able to read the cultural signs embodied in acts of meaning-making. The third element of the model, the critical, emphasizes the need for critical engagement with texts and artifacts of all kinds and the need to ask questions about power, about the intended audience, and about reception. In conclusion, as students engage in making activities, they need to draw on various knowledge and skills (operational) to inform their creative production (cultural) and thus come to understand the ways in which this knowledge is embedded in larger sociocultural contexts (critical). It is these three inter-related dimensions of maker literacy (operational, cultural, and critical) that our study addressed in the context of the elementary school's makerspaces and examined in relation to students' digital competence.

STUDY

Research Setting

Our study was situated in a city-run comprehensive elementary school in the capital region of Finland. The students come to school from the local catchment area and represent diverse socioeconomic and cultural backgrounds. The school strives for student-centeredness and design thinking across the curriculum. In 2016, the school introduced a novel makerspace, the FUSE Studio (www.fusestudio.net), into its educational program as one of its elective courses for students in Grades 4–6. The FUSE Studio was seen to respond well to the requirements of the Finnish core curriculum including the promotion of students' digital and other transversal competence.

The FUSE Studio introduces students to a range of STEAM topics, skill sets, and learning goals through design challenges (Stevens and Jona, 2017). The FUSE Studio includes various digital technologies and materials for students to use. Students can access the design challenges through a website. On this website, the students can watch trailers of each of the design challenges and choose the challenge that is the most appealing to them. The website includes instructions and video tutorials around the design challenges. The students can document their maker work through photos and videos retained in their personal accounts.

According to the developers of the FUSE Studio (Stevens and Jona, 2017), three main lines of research affected its development. First, the designers wanted to invent an alternative, interest-driven way for students to participate in STEM learning through art and design (i.e., STEAM). Second, the designers wanted to enhance connected, peer-based learning that could result in relative expertise, that is, students developing expertise relative to each other through peer collaboration. Thus, the developers proposed a new role for teachers as facilitators of students' peer collaboration and relative expertise. According to the developers, teachers need to take a new role in the FUSE Studio to facilitate students' peer collaboration and relative expertise instead of instructing them. Third, the FUSE Studio benefits from video game design principles by introducing students to challenges of increasingly difficult levels. This is expected to promote students' voluntary and persistent engagement (Stevens and Jona, 2017).

Participants and Design Challenges

Our study focused on 11 students (six females and five males) aged nine to 12 years old in the FUSE Studio, working on their self-chosen design challenges either individually, in pairs, or in small groups. The students were selected for this study from a larger data corpus (N:94) from our ethnographic data covering three groups of students who attended the FUSE Studio for a weekly 45–60-min session over the school year. The selection of these 11 students was based on the design challenges the students chose to work on as each of the challenges involved active use of various digital technologies.

The six design challenges the students worked on in our study were *Dream Home*, which invites students to design their dream home in 3D; *Music Amplifier*, which invites students to build an amplifier for their phone, mp3 player, or computer; *Keychain Customizer*, which invites students to design and 3D print a keychain with their name or custom message; *LED Color Lights*, which invites students to combine and control light from three LEDs to produce a rainbow of colors; *Ringtones*, which invites students to mix their own custom ringtone; and *Electric Apparel*, which invites students to customize their clothing and accessories so that they light up when they use them. For a full summary description of the design challenges, see **Table 1**.

Data Collection

The data were collected through videoing the students' activities in the FUSE Studio from August 2016 to May 2017. This long-term data collection allowed us to collect rich data of the students' maker activities. Five researchers took responsibility for the video data collection during each session by using four mobile cameras. The recording of each weekly session lasted from 45 to

TABLE 1 | Description of the FUSE design challenges.

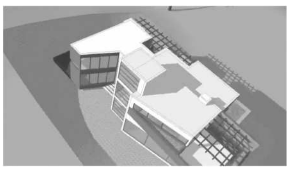
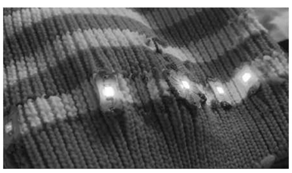
Challenge	Picture	Description	Tools used
Dream home		The students use 3D design software to design and build their "Dream Home."	Computer, Sketch-up software
Electric apparel		The students use LED lights and conductive thread to customize clothing. The aim is to re-use an existing piece of clothing and change it to include LEDs that light up when the accessory is used.	Computer, fabric, needle, thread, conductive thread, LED lights
Keychain customizer		The students use 3D design software to design a keychain model with their own name or custom message. The model is then printed using a 3D printer.	Computer, Sketch-up software, 3D printer
LED color lights		The students connect LED lights to a breadboard and program them to light up in a certain way using a computer program.	Computer, breadboard, LED lights
Music amplifier		The students use small speakers, electric wire, breadboard, and a battery to build a music amplifier which they can connect to their personal mobile devices.	Computer, phone or other small device, small speaker, electric wire, breadboard, a battery
Ringtones		The students use audio mixing software to design their own custom ringtone.	Computer, audio mixing software

TABLE 2 | Summary of the data set.

Dataset	Participants	Challenge	Video data
Dataset 1	One male student (Ilmari)	Ringtones and music amplifier	1 h, 30 min of video which depict the student's work on two design challenges across the fall semester
Dataset 2	Two male students (Markus and Antti)	Dream home	2 h of video from the students' joint work on a design challenge from the beginning and middle of the fall semester
Dataset 3	Two male students (Alexander and Lassi)	Keychain customizer	1 h of video which depicts the students' joint design and making process, beginning from taking up the challenge to 3D printing their keychains
Dataset 4	Four female students (Emmi, Silja, Nora, and Nellie)	LED color lights, ringtones, keychain customizer, electric apparel	30 min of video during which the students work on their design challenges on a shared table
Dataset 5	Two female students (Alma and Tanja)	Dream home	30 min of video of two students working on their design challenges

60 min. The whole data corpus of our study consists of 142 h of video recordings. The main principle that guided the decisions regarding the focus of the cameras for each session was motivated by the need to form a comprehensive picture of the nature of interactions and activities in the FUSE Studio. To support the data collection, we produced an Excel spreadsheet that identified the students, the teachers, and the FUSE challenges that the students' chose to work on during each session. The spreadsheets guided the focus of the video cameras for the next session and later supported the analysis of the collected video data. Capturing all the activities and interactions was a challenging endeavor because of the movements of students, student groups, teachers, and materials in the makerspace. Therefore, we understand the limitations of our study in documenting the complexity of ongoing activities through the chosen means.

Data Analysis

Our analysis proceeded by analyzing the video data through three sequential phases. The first phase involved reading the whole data corpus of 142 h to identify students who worked on those design challenges that involved active and sustained use of digital technologies. Based on a consensus negotiation within our research group, the first phase of our analysis resulted in choosing 11 students working on six design challenges. This accounted for 5 h and 30 min of video data. **Table 2** summarizes our data set.

The second phase of data analysis was abductive (Dey, 2003), and it involved coding the videos for three overarching categories, namely, operational, cultural, and critical, following Green's 3D original model of literacy (Green, 1988; Marsh, 2020). We also engaged in relating our analysis to the existing literature on the definitions of digital competence (Carretero et al., 2017). At the same time, we conducted emic, data-driven analysis of the video data to discover interactions that were unique to the makerspace context and which had not necessarily been identified by earlier research literature. These interactions and definitions that emerged from the video data were compared, discussed, and elaborated, and discrepancies in interpretations were solved within our research group. Agreed-upon definitions were compiled into the analysis framework used in the third phase of our analysis, entailing etic, top-down analysis.

During the etic analysis, a primary coder analyzed videos using the Atlas.ti qualitative analysis software, applying our emergent analysis framework. As maker literacies are multimodal in nature, the analysis of the students' maker practice followed multimodal interaction analysis (Kress, 2010; Streeck et al., 2011; Taylor, 2014) that takes into account the students' verbal and non-verbal interaction, including their temporal coordination of their gestures and talk along with the handling of the materials. As the analysis progressed, analysis descriptions and coding rules were further clarified and revised in conversations within our research team. The data were analyzed iteratively to reflect the latest decision rules until the analysis was finalized. To establish reliability of the analysis, the second coder scored a representative sample of the same data by applying the finalized analysis framework. Any disagreements in coding were discussed by the research team until there was 100 per cent agreement. The disagreements between the researchers concerned how to code the data when the same instance of interaction could be coded to more than one category. At times, defining what accounted as an instance of interaction also required negotiation. As the result of our joint negotiations, we defined an instance of interaction as "a meaningful unit of analysis" with a detectable beginning and end. After reaching a consensus with all parts of our analysis, a final review of coding was conducted to ensure that the analytical procedures reflected the final analysis framework and its rules.

RESULTS

Our multi-phase analysis of the students' maker literacies in the FUSE Studio resulted in an analysis framework shown in **Table 3**. In this analysis framework, the *operational dimension* refers to students using digital tools, creative, and playful engagement with digital tools, identifying digital resources and tools, making informed decisions as to which are the most appropriate digital tools according to the purpose or need, solving problems through digital means, solving technical problems, and engaging in updating one's own and others' digital skills and related knowledge. The *cultural dimension* of maker literacies refers to using, producing, and making sense of digital technologies and content in relation to cultural context. The dimension covers playing and experimenting with digital tools; communicating and collaborating with digital tools and in digital environments; creating and editing digital content by taking account of the audience; integrating and re-elaborating previous knowledge, experiences, and content; producing creative expressions through digital tools, media

TABLE 3 | An analysis framework of maker literacies.

Category	Description	Illustrative example
Operational	• Using digital tools • Playing and experimenting with digital tools • Identifying digital resources and tools • Making informed decisions as to which are the most appropriate digital tools according to the purpose or need • Solving problems through digital means • Solving technical problems • Engaging in acquiring digital skills and related knowledge	*Ilmari is connecting different parts of the music amplifier, reading and following the instructions carefully from his laptop screen. He tries to play some music and puts the speaker next to his ear and listens carefully. He points out quietly to himself "not working" and continues intently working to solve the problem.*
Cultural	• Using, producing and making sense of digital technologies and content in relation to a cultural context • Communicating and collaborating with digital tools and in digital environments • Creating and editing digital content by taking account of the audience and integrating and re-elaborating previous knowledge, experiences, and content • Producing creative expressions through digital tools, media outputs, and programming • Considering the aesthetics of digital content and tools • Linking with others and collaborating through digital tools • Demonstrating cross-cultural awareness • Dealing with and applying intellectual property rights and licenses	*Alma is working on the Dream Home challenge on a computer, next to her friend Tanja. Alma finds a new function on how to choose between color tones and building materials. She rejoices, "Ooh, now I know," at the same time standing up to eagerly point at Tanja's computer screen, advising her to "Go to the bucket…to that plus sign."*
Critical	• Judging and evaluating digital technologies and digital content • Identifying the intentions of designers and producers and how they position an audience • Considering issues of power, equity and diversity, persuasion, propaganda, and trust • Considering issues around safety by paying attention to personal protection, data protection, digital identity protection, security measures, and safe and sustainable use of digital technologies	*Markus is showing Henri how to open his earlier saved Dream Home design challenge on his computer. Markus clicks on a logo on the computer screen and a new window opens, asking him to accept the program's terms and conditions. Markus is asking Henri for his permission to do this by reading out loud, "I am signing under these?" Henri laughs a bit and answers, "Yes." Markus makes sure of this by asking, "So you are now signing under these?" Henri responds again by laughing a bit.*

outputs, and programming; and considering the aesthetics of digital content and tools. It also involves connecting with others and collaborating through digital tools, interacting with and participating in communities and networks demonstrating cross-cultural awareness, and dealing with and applying intellectual property rights and licenses. The *critical dimension* refers to judging digital tools and digital content; identifying the intentions of designers and producers and how they position an audience; and considering issues of power, equity and diversity, persuasion, propaganda, and trust. It also involves considering issues around safety by paying attention to personal protection, data protection, digital identity protection, security measures, and safe and sustainable use of digital technologies.

Students' Maker Literacies in the FUSE Studio

Using our analysis framework, we identified 199 instances of operational, cultural, and critical dimensions in the students' interaction in the FUSE Studio in our chosen data set covering 5 h and 30 min of video data. The operational dimension of maker literacies was found to be the most frequent dimension, covering 74 per cent (N:147) of the students' multimodal interaction, whereas the cultural (16%, N:31) and critical (10%, N:21) dimensions covered a quarter of the students' multimodal interaction (see **Figure 1**). These results indicate that the FUSE Studio created a fertile learning environment for the enhancement of the students' digital competence, particularly that competence that relates to operational literacies.

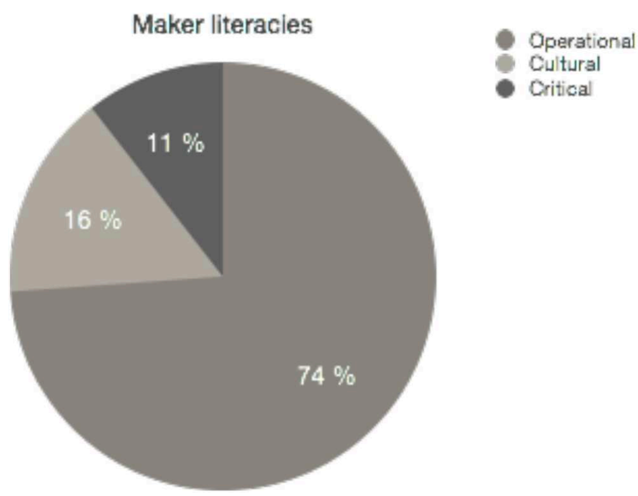


FIGURE 1 | The nature of maker literacies in the FUSE studio.

Our findings also show how the six design challenges on which the students worked in the FUSE Studio promoted different dimensions of maker literacies in the students' multimodal interaction (see **Table 4**). The operational dimension was the most frequent dimension of the students' maker literacies across the different challenges.

Our contrastive analysis between the datasets shown in **Table 4** reveals how the content and context of the students'

TABLE 4 | Maker literacies across the design challenges and students.

Categories	Dataset 1	Dataset 2	Dataset 3	Dataset 4	Dataset 5	Total
Operational	48 (84%)	21 (54%)	44 (82%)	17 (68%)	17 (71%)	147 (74%)
Cultural	6 (11%)	11 (28%)	4 (7%)	4 (16%)	6 (25%)	31 (16%)
Critical	3 (5%)	7 (18%)	6 (11%)	4 (16%)	1 (4%)	21 (10%)
Total	57 (100%)	39 (100%)	54 (100%)	25 (100%)	24 (100%)	199 (100%)

maker activity was associated with the nature of their maker literacies. For example, the Dream Home design challenge showcased somewhat different dimensions of maker literacies between the student groups (see Datasets 2 and 5). In Dataset 2, 18 per cent of the identified instances of the students' maker activity during the Dream Home challenge were to do with critical literacies, whereas in Dataset 5, critical maker literacies accounted for 4 per cent of the students' behavior during the same design challenge. These findings point to the importance of paying attention to the content and social context of students' maker activities for their maker literacies and enhancing digital competence. Our analysis also points out the need to take account of the processes and different phases of students' maker practice in efforts to understand maker literacies in full as these evolve *in situ* and over time. In this connection it is appropriate to recognize that our data come from the 1st year of implementing the FUSE Studio in the school and hence the FUSE challenges were new to the students. It is possible that this newness of the makerspace and its challenges impacted the students' frequent engagement in the operational literacies as they were learning to use the novel digital tools and solving novel challenges. Last but not least, we acknowledge our small dataset and hence consider our findings as hypothetical and worthy of more research attention.

Analyzing the frequency of students' maker literacies across operational and cultural literacies provided a valid measure for our study, one allowing for possibilities and limitations (Ryan and Bernard, 2000). The frequencies are helpful in creating general knowledge of how different makerspaces and their design activities produce opportunities for maker literacies. However, we believe qualitative insights are also needed to explain quantitative findings and to understand the situated nature of maker literacies. We now turn to illuminating our findings with qualitative examples.

Maker Literacies in Practice: Illustrative Vignettes

We use vignettes to illustrate our findings on the different dimensions of students' maker literacies in the FUSE Studio. The vignettes were chosen as representative cases found in our data (Patton, 2002). They illuminate the dynamics and inter-relations of operational, cultural, and critical literacies in the students' maker activities and how these relate to digital competence.

Vignette 1: Documenting Maker Work

Our first vignette is from Dataset 4 in which four students, Silja, Nellie, Emmi, and Nora, are working together on the LED Color Lights design challenge (see **Figure 2** and **Table 5**). The design challenge involves connecting LED lights to a breadboard and programming them to light up according to the students' design. Our example illustrates a frequent presence of operational literacies in the students' maker activity, infused with cultural, and critical literacies.

The students are working on the final phase of their design challenge, documenting their work on their personal accounts in the FUSE Studio. Emmi grabs a camera that Nora used earlier. Meanwhile, Silja is adjusting some parts in her hands and Emmi is reading the FUSE challenge instructions from the laptop. Before taking a picture of their design, Emmi and Silja carefully connect the LED parts in their design until a green light turns on. Emmi is also asking the other students if it is possible to make a video of their maker work with the camera (Line 1: *How do we make a video from this?*). Silja responds to Emmi's question, advising her that the camera does not allow her to take a video of their work (Line 2: *Hmmm, you cannot make a video with it.*). Emmi and Silja discuss the use of the camera while Emmi takes a picture of the students' LED light design to be documented on the FUSE Studio website. Emmi and Silja then examine the picture carefully from the camera's screen to determine its quality and to meet the requirements of the design challenge. Silja's comment in Line 3 (*Well, that's good.),* together with the students' non-verbal actions evidence their involvement in judging the quality of their work.

The vignette shown in **Table 5** highlights the strong presence of the operational dimension of maker literacies in the students' activity as they documented their work. The students used various digital tools and resources: the camera, LED lights, breadboard, the FUSE instructions, and the laptop. The students also jointly considered and evaluated the outcome of their maker activity through their documentation, hence they also engaged in cultural and critical literacies.

Vignette 2: Imagining the Future of 3D Printing

The second vignette is from Dataset 3 in which two students, Alexander and Lassi, are working together on the Keychain Customizer design challenge (see **Figure 3** and **Table 6**). This design challenge involves the students using 3D design software to design a keychain model with their own name or custom message. The model is then printed using a 3D printer.

In the vignette, other students from the class have joined Alexander and Lassi to observe and video record the processes of 3D printing of the keychains they designed with their mobile phones. The teacher, Nils, also joins the students, and he initiates a conversation on 3D printing by asking the students to share

FIGURE 2 | Students working on the LED color lights design challenge.

TABLE 5 | Documenting maker work.

Line	Speech/ vocalization	Actions	Gaze	Gesture, facial expressions
1	*Emmi: how do we make a video from this?*	Emmi: Carefully connects LED parts in her hands until a green light turns on, then grabs the camera and looks at the camera screen.	Emmi: Gazes at the camera.	
2	*Silja: Hmmm, you cannot make a video with it.*	Silja: Moves closer to Emmi and looks at the camera screen as Emmi is taking a picture. Emmi: Takes a picture of the designed LED artifact.	Silja: Gazes at the objects on the table, then glances at Emmi and at the camera. Emmi: Gazes at the camera screen.	
3	*Silja: well, that's good.*	Silja: Looks at the picture on the camera screen, then leans back but moves back closer to Emmi to look again at the camera and the picture. Emmi: Turns the camera in her hands and looks at the camera screen.	Silja: Looks at the camera screen, then turns gaze to the LED lights and again back to the camera screen. Emmi: Gazes at the camera.	

FIGURE 3 | Students working on the keychain customizer design challenge.

TABLE 6 | Imagining the future of 3D printing.

Line	Speech/ vocalization	Actions	Gaze	Gesture, facial expressions
1	*Nils: What objects do you think could be made with this one day?*	Nils: Stands next to the printer. Lassi: Stands in front of the printer, looks at the printer. Other Students: stand around the printer. Follow the printing, make and watch videos of the printing.	Nils: Looks at the 3D printer, then turns his gaze to all the students to ask a question. Lassi: Gazes at the printer. Other Students: gaze at the phone screens and at the printer.	Nils: Smiles.
2	*Mike: Well, today we can 3D print even food.*	Mike: Looks first at his phone, then puts his phone in his pocket as he joins the conversation. Nils: Stands next to the printer.	Mike: Looks at the 3D printer, then turns his gaze to the teacher. Nils: Gazes at Mike.	Mike: Smiles and laughs. Nils: Smiles.
3	*Lassi: Oh!*		Lassi: Turns his gaze first toward Arto and then toward Mike.	Lassi: Looks at Mike and raises his hand.
4	*Mike: A 3D printer has printed a pizza.*	Mike, nils, and Lassi: Stand next to the printer.	Mike: Gazes at the teacher. Nils: Gazes at Lassi. Lassi: Gazes at the teacher.	
5	*Lassi: Can a 3D printer print a car that works?*	Lassi, nils, and Mike: Stand next to the printer.	Lassi: Gazes at the teacher whilst asking the question. Nils: Gazes at Lassi. Mike: Gazes at the teacher.	Lassi: Raises both arms with flat hands and makes a shoulder shrug. Nils: Smiles.
6	*Nils: Yeah, it could.*	Nils: Stands in front of the printer.	Nils: Gazes at Lassi. Lassi: Gazes at the teacher.	Nils: Smiles.
7	*Mike: Maybe today it is possible somewhere...*	Elmo: Puts the phone down when joining the conversation. Nils: Stands in front of the printer.	Nils: Gazes at Mike. Elmo: Turns his gaze away from the phone and toward the teacher when explaining.	Nils: Smiles.
8	*Elmo: At least the frame of a car.*	Nils: Stands in front of the printer. Elmo: Stands in front of the printer.	Nils: Gazes at Mike and then looks down at the printer. Elmo: Turns his gaze away from the phone and toward the teacher when explaining.	Nils: Smiles. Arto: Smiles when looking at the 3D printer.

what they think 3D printing could be used for in the future (Line 1: *What objects do you think one day could be made with this?*). This question evokes the students' imagination as they start to consider the future of 3D printing. At the same time, the students share their knowledge about the ways in which 3D printing is used today in society (Lines 2–8).

In the vignette shown in **Table 6**, we can see the cultural dimension of literacy when the students are imagining the present and future of 3D printing. The students' own initiation to video 3D printing processes and to share these videos with each other can also be construed as evidence of the students' engagement in cultural literacies. We can also trace cultural literacies being infused with critical literacies in this vignette, as the students are considering the options and challenges of 3D printers today and in the future. For example, they are considering whether it is possible to 3D print a functioning car (Lines 5–8).

Vignette 3: Can I Design This With a Flat Roof?

The third vignette is from Dataset 2 in which two students, Antti and Markus, are working on the Dream Home design challenge on their computers (see **Figure 4** and **Table 7**). This design challenge involves the students using 3D design software to design and build their "Dream Home."

Markus starts a discussion with Antti and asks if the maker challenge could be realized without making a gabled roof as suggested by the FUSE Studio instructions, but with a flat roof instead (Line 1: *Can I do this with a flat roof?*). Antti replies that in his design he has made a flat roof and hence he did not follow the instructions (Line 2: *Yeah, I also did it with a flat roof.*). Markus continues seeking assurance from Antti and repeats his question whether altering the roof design is something they are allowed to do (Line 3: *Can we do it that way?*). Antti replies shortly and confirms with a laugh that it is allowed.

This vignette gives an example of the students' engagement in the critical dimension of maker literacies as they are questioning the instructions of the Dream Home design challenge and incorporating their own interests and preferences into their maker activity. Although the episode is short, it shows how the social context and peer interaction around the maker activity opened up a space for the students' engagement in critical literacy and jointly confirming alternative, more meaningful ways of designing their dream homes with the 3D design software. They are also considering issues of power, freedom, and authority, whilst reflecting on what they are allowed to do in the FUSE Studio and its design challenges.

DISCUSSION

Although many young people in the Global North have opportunities to use and interact with digital technologies,

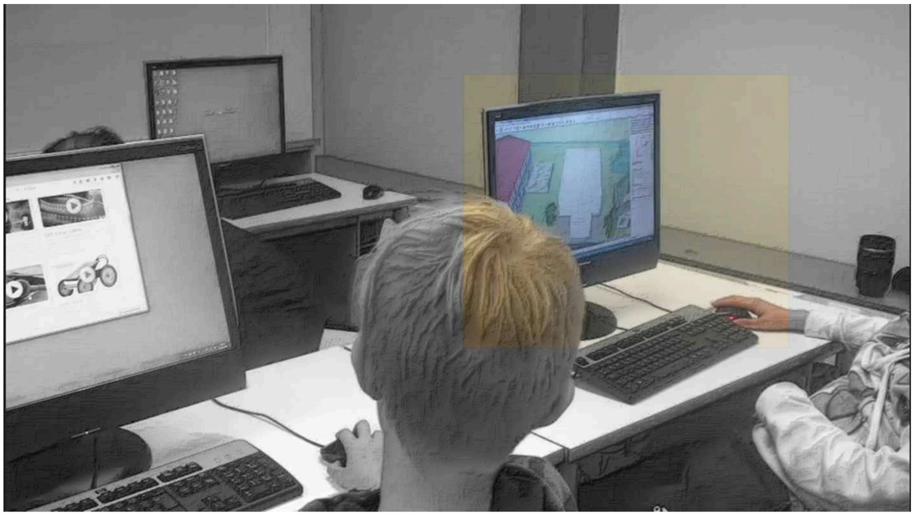


FIGURE 4 | Students working on the dream home design challenge.

TABLE 7 | Can i do this with a flat roof?

Line	Speech/ vocalization	Actions	Gaze	Gesture, facial expressions
1	*Markus: Can I do this with a flat roof?*	Markus: Sits in front of the computer, clicks the mouse a few times and moves it a bit, not making any visible changes to the house. Antti: Sits in front of the computer, investigates different FUSE design challenges.	Antti: Gazes at the screen and then turns his gaze to Markus as he is asking a question.	
2	*Antti: Yeah, I also did it with a flat roof.*	Markus: Sits in front of the computer, not making any visible changes to the house. Antti: Scrolling a page on the FUSE Studio website and opening a video.	Antti: Turns his gaze toward the screen to watch a video. Then turns his gaze to Markus and back at the screen.	Antti: Laughs.
3	*Markus: Can we do it that way?*	Markus: Sits in front of the computer, not making any visible changes to the house. Antti: Clicks a video on the FUSE Studio website.	Antti: Gazes at the screen.	

research indicates that young people's digital engagement is mostly about consumerism, whereas more active, creative, and critical engagement with digital technologies is scarce (Ala-Mutka, 2011). Furthermore, research indicates that there is an uneven provision of digital learning opportunities in young people's social ecologies (Palaiologou, 2016; Livingstone et al., 2017), pointing to the need to ensure every student's right to improve their digital competence as part of their education. Moreover, at present there is a dearth of knowledge about creating digital learning opportunities that are inclusive for diverse learners with different capabilities and interests (Blikstein and Worsley, 2016; Kumpulainen and Erstad, 2017).

In this study, we investigated the enhancement of young students' digital competence in an elementary school's makerspace in Finland. Drawing on sociocultural theorizing and studies of digital literacy, the core focus has been on students' maker literacies across operational, cultural, and critical dimensions. In our work, maker literacies are understood as social practices that entail making and remaking artifacts and texts using various materials and technologies. Maker literacies hence draw on a range of semiotic systems and multimodal resources across operational, cultural, and critical dimensions (Green, 1988; Sefton-Green et al., 2016; Marsh, 2020). By following this theoretical framing and a detailed multimodal analysis of ethnographically collected video data, we were able to develop a framework of analysis for researching and understanding students' maker literacies and the construction of digital competence in the makerspace context. The framework we developed offers a holistic approach to researching and understanding students' digital competence in makerspaces, expanding traditional conceptualizations of digital literacy, and digital skills.

The makerspace context of our study was a FUSE Studio, a digital infrastructure for STEAM learning with several design challenges (Stevens and Jona, 2017). Hence, the results of our study need to be situated in this context. Earlier research has pointed out how makerspaces can differ in their organization, content, activities, pedagogical design, and goals, availability, and the distribution of materials and resources (Peppler et al., 2016; Hughes et al., 2019; Blum-Ross et al., 2020). For this reason, makerspaces should not be automatically understood as uniform spaces that are comparable to one another. Instead, more research is needed about different variations of makerspaces and how they create opportunities for students' maker literacies, digital competence, and learning at large.

Our study indicates that the FUSE Studio, as a form of makerspace, supported the students' frequent engagement in the operational dimension of literacies. The FUSE Studio and its design challenges engaged the students in identifying and using various digital tools in their design activities that also involved active problem solving. In addition, we observed the students solving technical problems as well as building their knowledge and skills in relation to using and understanding digital tools in and for their maker activities. These are all important elements of the students' emerging digital competence (Carretero et al., 2017). The students' active and persistent engagement in the operational dimension of maker literacies was supported by the design of the FUSE Studio that had several resources available for the students to enhance their maker activities and learning processes, such as video tutorials and written instructions. These multiple resources also supported the students' ownership of their maker activities (see also Stevens and Jona, 2017). Similarly, peer tutoring and the teachers' support played a role in fostering the students' engagement in the operational dimensions of maker literacies in the FUSE Studio. These findings point out the role of the social context and the human and material resources available within the makerspace in creating opportunities for the enhancement of students' maker literacies and digital competence.

Our findings show how the makerspace comprised a complex set of activities that encompassed not only the operational dimensions of maker literacies, but also to some extent cultural processes surrounding the use and construction of digital technologies. Like earlier research (Burke and Crocker, 2020), we identified exploration with digital tools in which the students positioned themselves as designers and creators instead of consumers of digital technologies. The cultural dimension of maker literacies also accounted for the students developing and devising expansive ways to use digital tools in their creative activities. At the same time, this involved the students considering the affordances of different modes and media in and for their maker work. In addition, we identified the students communicating and collaborating with and around the digital tools, creating, and editing digital content, integrating, and re-elaborating previous knowledge, and experiences, and producing creative expressions with digital tools. We also observed the students considering the aesthetics of digital content and tools, an area that has so far received too little attention in the research on makerspaces (Kafai et al., 2014). However, demonstrating cross-cultural awareness and considering intellectual property rights and licenses were scarce in our data. In all, the proportion of cultural literacies compared to operational literacies was small in our data. This outcome deserves further research attention.

Our results indicate that the students' engagement in the critical dimensions of maker literacies was similarly scant compared to the operational literacies. There were few instances in which we observed the students analyzing or judging digital technologies or digital content. Neither did we often find the students addressing issues of power or persuasion in their maker activities. Paying attention to safety issues such as personal protection, data protection, and safe and sustainable use of digital technologies was also limited in the students' maker literacies. These findings are like those from the research literature that pointed out how maker activities can easily involve more "doing" and less "thinking and reflection" (Blikstein and Worsley, 2016). Furthermore, in our study, we observed the students orienting their maker work toward the end product and not engaging very deeply in reflecting on the actual processes of making. A focus on the outcome may have encouraged the students to engage more in operational literacies instead of critical or cultural literacies. Therefore, we concluded that more attention needs to be given to maker education and the design of makerspaces and their activities in supporting students in taking a more critical stance toward their maker work, including analyzing and evaluating digital tools and content.

CONCLUSIONS

The results of our study show that the FUSE Studio makerspace offered a fertile context for the students to engage in operational literacies and to some extent also in cultural and critical literacies. The identified maker literacies resonate with many of the digital competencies listed in the research literature (Carretero et al., 2017), namely, problem-solving, communicating, and collaborating, and digital content creation. However, maker literacies that were related to cultural and critical maker literacies, including consideration of digital safety, were scarce and hence they require more pedagogical and educational design attention in the future. We also call for more longitudinal, multi-year investigations into students' maker literacies in makerspaces as the novelty of the makerspace and its design challenges is likely to have an impact on students' maker literacies across operational, cultural, and critical dimensions. As the analysis framework we have developed is new, there is also a need to test and use this analytic mapping tool in different makerspace contexts in order to determine how the three dimensions of maker literacies occur in the students' interactions. Further, it is important to recognize that the content and context of maker activities interacts with the students' maker literacies, hence the analysis framework should not be used to determine "the level" of students' digital competence without recognition of the structural and material features of the social context in which students design and make.

While our findings are descriptive and stem from a small data sample, the analysis framework we developed as part of our study may be useful for future research on maker literacies as they relate to students' digital competence in and across makerspaces. Our framework is not designed to offer an exhaustive model of maker literacies; rather, it outlines some of the skills, knowledge, and understanding that students potentially employ when engaging in design and making activities in makerspaces with attention to the inter-related dynamics between operational, cultural, and critical dimensions that account for digital competence. The knowledge generated through the analysis framework can offer insights into research and teacher education programs, curriculum development, and the design of makerspaces in and out of schools. In the future, this analytic framework could be developed further to better account for the dynamic relations between maker literacies, digital competence, and students' learning processes in science, technology, engineering, arts, and mathematics.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because, we do not have ethics approval to share the raw video data from the current study. Requests to access the datasets should be directed to KK, kristiina.kumpulainen@helsinki.fi.

ETHICS STATEMENT

We do not have ethics approval to share the raw data from the current study as it consists of video data of children aged 9–12 years old. The study follows the ethical standards of scholarly research established by the Finnish Advisory Board on Research on Integrity (https://www.tenk.fi), Data Protection Act and the Convention on the Rights of the Child. The Education Division of the City of Helsinki reviewed and approved the study. Informed consent was obtained from all adult and youth participants and youth guardians. Pseudonyms were used for all individuals.

AUTHOR CONTRIBUTIONS

KK was responsible for framing, conceptualizing, and formulating the study, including its theoretical and methodological approaches, as well as analysis and interpretation of the empirical data. She also took major responsibility for writing up the manuscript. AK contributed to the literature review and argumentation logic of the manuscript. JL contributed to the literature review, data collection, and description of the empirical study. JB and JR contributed to the analysis and reporting of the empirical findings of the study as well as editing the manuscript.

FUNDING

The research reported in this chapter was funded by the Academy of Finland Learning by Making: The educational potential of school-based makerspaces for young learners' digital competencies (iMake) project during the period of 2017-2020 (no: 310790); PI KK.

University of Helsinki: Contribution to publishing in open access journals.

REFERENCES

Ala-Mutka, K. (2011). *Mapping Digital Competence: Towards a Conceptual Understanding*. Publications Office of the European Union. Available online at: ftp://jrc.es/pub/EURdoc/JRC67075_TN.pdf (accessed March 21, 2020).

Barton, D. P., Hamilton, M. E., and Ivanic, R. (2000). *Situated Literacies*. London: Routledge.

Blikstein, P., and Worsley, M. (2016). "The Maker Movement: The last chance of progressive education?" in *Makeology: Makerspaces as learning environments*, eds K. Peppler, E. Halverson, and Y. Kafai (New York, NY: Routledge), 64–80.

Blum-Ross, A., Kumpulainen, K., and Marsh, J. (2020). *Enhancing digital literacy and creativity: Makerspaces in the Early Years*. London: Routledge. doi: 10.4324/9780429243264

Buechley, L., Peppler, K., Eisenberg, M., and Kafai, Y. (2013). *Textile messages: Dispatches from the world of e-textiles and education*. New York, NY: Peter Lang. doi: 10.3726/978-1-4539-0941-6

Burke, A., and Crocker, A. (2020). "Teaching for social imagination: Creativity in an early-learning makerspace," in *Enhancing digital literacy and creativity: Makerspaces in the Early Years*, eds A. Blum-Ross, K. Kumpulainen, and J. Marsh (London: Routledge), 165–181. doi: 10.4324/9780429243264-11

Burnett, C. (2016). Mapping multiple literacies: an introduction to deleuzian literacy studies. *Literacy* 50, 50–51. doi: 10.1111/lit.12034

Burnett, C., Merchant, G., Pahl, K., and Rowsell, J. (2014). The (im)materiality of literacy: the significance of subjectivity to new literacies research. *Discour. Stud. Cult. Politics Educ.* 35, 90–103. doi: 10.1080/01596306.2012.739469

Carretero, S., Vuorikari, R., and Punie, Y. (2017). *DigComp 2.1: The Digital Competence Framework for Citizens With Eight Proficiency Levels and Examples of Use*. Luxembourg: Publications Office of the European Union. Available online at: http://svwo.be/sites/default/files/DigComp%202.1.pdf (accessed March 21, 2020).

Chaudron, S., Di Gioa, R., and Gemo, M. (2018). *Young Children (0-8) and Digital Technology, A Qualitative Study Across Europe*. Publications Office of the European Union.

Dey, I. (2003). *Qualitative Data Analysis: A User-Friendly Guide for Social Scientists*. New York, NY: Routledge. doi: 10.4324/9780203412497

EU Kids Online (2014). *EU Kids Online 2014: Findings, Methods, Recommendations*. Available online at: http://lsedesignunit.com/EUKidsOnline/ (accessed March 23, 2020).

Ferrari, A. (2013). *DIGCOMP: A Framework for Developing and Understanding Digital Competence in Europe*. Publications Office of the European Union.

Finnish National Agency for Education (2016). *National Core Curriculum for Basic Education 2014*. Finnish National Agency for Education.

Gee, J., Hull, G., and Lankshear, C. (1996). "Sociocultural literacy, discourses, and the new work order," in *The New Work Order*, ed. J. Gee (London: Routledge). doi: 10.4324/9780429496127

Green, B. (1988). Subject-specific literacy and school learning: a focus on writing, *Aust. J. Educ*. 32, 156–179. doi: 10.1177/000494418803200203

Guyotte, K. W. (2020). Toward a philosophy of STEAM in the Anthropocene. *Educ. Philos. Theory*. 52, 769–779. doi: 10.1080/00131857.2019.1690989

Hakkarainen, K., Hietajärvi, L., Alho, K., Lonka, K., and Salmela-Aro, K. (2015). "Socio-digital revolution: digital natives vs. digital immigrants," in *International Encyclopedia of the Social and Behavioral Sciences, 22nd Edn*. ed J. D. Wright (Amsterdam: Elsevier), 918–923. doi: 10.1016/B978-0-08-097086-8.26094-7

Halverson, E., and Sheridan, K. (2014). The maker movement in education. *Harv. Educ. Rev*. 84, 495–504. doi: 10.17763/haer.84.4.34j1g68140382063

Honey, M., and Kanter, D. E. (2013). *Design, Make, Play: GROWING the Next Generation of STEM Innovators*. New York, NY: Routledge. doi: 10.4324/9780203108352

Hughes, J., Morrison, L., Kajamaa, A., and Kumpulainen, K. (2019). "Makerspaces promoting students' design thinking and collective knowledge creation: examples from Canada and Finland," in *Interactivity, Game Creation, Design, Learning, and Innovation*, eds A. Brooks, E. Brooks, and C. Sylla, ArtsIT 2018, DLI 2018. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, 265. (Cham: Springer), 343–352. doi: 10.1007/978-3-030-06134-0_38

Ilomäki, L., and Lakkala, M. (2011). "Koulu, digitaalinen teknologia ja toimivat käytännöt," in *Opetusteknologia koulun arjessa II*, eds. M. Kankaanranta and S.Vahtivuori-Hänninen (Koulutuksen tutkimuslaitos: Jyväskylän yliopisto), 47–67.

Jenkins, H., Clinton, K., Purushotma, R., Robison, A. J., and Weigel, M. (2009). *Confronting the Challenges of Participatory Culture: Media Education for the 21st Century. An Occasional Paper on Digital Media and Learning*. Available online at: http://digitallearning.macfound.org/atf/of/%7B7E45C7E0-4B89-AC9C-E807E1B0AE4E%D/JENKINS-WHITE-PAPER.pdf (accessed March 21, 2020).

Kafai, Y., and Burke, Q. (2015). Constructionist gaming: understanding the benefits of making games for learning. *Educ. Psychol*. 50, 313–334. doi: 10.1080/00461520.2015.1124022

Kafai, Y., Fields, D., and Searle, K. (2014). Electronic textiles as disruptive designs: supporting and challenging maker activities in schools. *Harv. Educ. Rev*. 84, 532–565. doi: 10.17763/haer.84.4.46m7372370214783

Kress, G. (2010). *Multimodality-A Social Semiotic Approach to Contemporary Communication*. London: Routledge. doi: 10.4324/9780203970034

Kumpulainen, K., and Erstad, O. (2017). (Re)Searching learning across contexts: conceptual, methodological and empirical explorations. *Int. J. Educ. Res*. 84, 55–57. doi: 10.1016/j.ijer.2016.08.004

Kumpulainen, K., and Renshaw, P. (2007). Cultures of learning. *Int. J. Educ. Res*. 46, 109–115. doi: 10.1016/j.ijer.2007.09.009

Litts, B. K. (2015). *Making learning: Makerspaces as learning environments*. (doctoral dissertation). The University of Wisconsin-Madison, Madison, United States.

Livingstone, S., Lemish, D., Lim, S. S., Bulger, M., Cabello, P., Claro, M., et al. (2017). Global perspectives on children's digital opportunities: an emerging research and policy agenda. *Pediatrics* 140, 137–141. doi: 10.1542/peds.2016-1758S

Ludvigsen, S., Lund, A., Rasmussen, I., and Säljö, R. (2011). *Learning Across sites: New Tools, Infrastructures and Practices*. London: Routledge. doi: 10.4324/9780203847817

Marsh, J. (2020). "Researching the digital literacy and multimodal practices of young children. A European agenda for change," in *The Routledge Handbook of Digital Literacies in Early Childhood*, eds O. Erstad, R. Flewitt, B. Kümmerling-Meibauer, and S. P. Pereira (London: Routledge), 19–30. doi: 10.4324/9780203730638-2

Marsh, J., Arnseth, H. C., and Kumpulainen, K. (2018). Maker literacies and maker citizenship in the MakEY (makerspaces in the early years) project. *Multimodal Technol. Inter*. 2:50. doi: 10.3390/mti2030050

Martin, L. (2015). The promise of the maker movement for education. *J. Pre College Eng. Educ. Res*. 5, 30–39. doi: 10.7771/2157-9288.1099

Palaiologou, I. (2016). Children under five and digital technologies: implication for early years pedagogy. *Eur. Early Childhood Res J*. 24, 5–24. doi: 10.1080/1350293X.2014.929876

Patton, M. Q. (2002). *Qualitative Research and Evaluation Methods (3rd ed.)*. Thousand Oaks: Sage.

Pawloski, L., and Wall, C. (2016). *Maker Literacy: A New Approach to Literacy Programming for Libraries*. Santa Barbara: Libraries Limited.

Peppler, K., Halverson, E., and Kafai, Y. (2016). *Makeology: Makerspaces as Learning Environments (Vols. 1 and 2).* New York, NY: Routledge. doi: 10.4324/9781315726519-1

Portelance, D. J., Strawhacker, A., and Bers, M. U. (2015). Constructing the ScratchJr programming language in the early childhood classroom. *Int. J. Technol. Design Educ*. 26, 489–504. doi: 10.1007/s10798-015-9325-0

Ratto, M. (2011). Critical making: conceptual and material studies. *Technol. Soc. Life* 27, 252–260. doi: 10.1080/01972243.2011.583819

Resnick, M., Berg, R., and Eisenberg, M. (2000). Beyond black boxes: bringing transparency and aesthetics back to scientific investigation. *J. Learn. Sci*. 9, 7–30. doi: 10.1207/s15327809jls0901_3

Rowsell, J., and Wohlwend, K. (2016). Free Play of Tight Spaces? *Mapping Participatory Literacies in Apps. Reading Teacher* 70, 197–205. doi: 10.1002/trtr.1490

Ryan, G. W., and Bernard, H. R. (2000). "Data management and analysis methods," in *Handbook of Qualitative Research*, eds. N.K. Denzin and Y.S. Lincoln (Thousand Oaks: Sage), 769–802.

Säljö, R. (1999). "Learning as the use of tools: a socio-cultural perspective on the human-technology link," in *Learning With Computers: Analysing Productive Interaction*, eds K. Littleton and P. Light (London: Routledge), 144–163.

Sefton-Green, J., Marsh, J., Erstad, O., and Flewitt, R. (2016). *Establishing a Research Agenda for the Digital Literacy Practices of Young Children: a White Paper for COST Action IS1410*. Available online at: http://digilitey.eu (accessed March 21, 2020).

Sheridan, K., Halverson, E., Litts, B., Brahms, L., Jacobs-Priebe, L., and Owens, T. (2014). Learning in the making: a comparative case study of three makerspaces. *Harv. Educ. Rev*. 84, 505–531. doi: 10.17763/haer.84.4.brr34733723j648u

Stevens, R., and Jona, K. (2017). *Program design. FUSE Studio Website*. Available online at: https://www.fusestudio.net/program-design (accessed March 21, 2020).

Streeck, J., Goodwin, C., and LeBaron, C. (2011). *Embodied Interaction: Language and Body in the Material World*. Cambridge: Cambridge University Press.

Suoninen, A. (2014). Lasten mediabarometri 2013. 0-8 vuotiaiden mediankäyttö ja sen muutokset vuodesta 2010. *Nuorisotutkimusseura, verkkojulkaisuja* 75.

Taylor, R. (2014). Meaning between, in and around words, gestures and postures-multimodal meaning-making in children's classroom discourse. *Lang. Educ*. 28, 401–420. doi: 10.1080/09500782.2014.885038

Vygotsky, L. (1987). *The collected works of L. S. Vygotsky (Vol. 1)*. New York, NY: Plenum Press.

Wohlwend, K., Scott, J., Yi, J., Deliman, A., and Kargin, T. (2018). "Hacking toys and remixing media: Integrating maker literacies into early childhood teacher education," in *Digital Childhoods: Technologies in children's everyday lives. International Perspectives on Early Childhood Education and Development, vol. 22, eds S.* Danby, M. Fleer, C. Davidson, and M. Hatzigianni (Singapore: Springer), 147-162.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.